NORTH BORDER RELATIONS OF THE TRIASSIC IN PENNSYLVANIA.

BY EDGAR T. WHERRY, PH.D.

The uniform gentle northwest dip of the Triassic Red-beds throughout the greater part of the belt crossing southeastern Pennsylvania has been a subject of comment since the earliest days of study of the region. Henry D. Rogers, in his final report,[1] cleverly suggested that it was due to inclined deposition, from northward-flowing waters, such as can be observed in present-day river deltas. The inadequacy of this explanation is made apparent, however, by the evident level-surface origin of the fossil footprints and rain-drop impressions which have since been found, as well as by the fact that in certain places, especially toward the northwest border of the belt, the dips show considerable variations, both in amount and direction.

No simple process of uplift and folding, however, can account for the relations observed. The fact that thousands of feet of strata exposed in the southern portion of this belt are totally lacking along its northern edge implies that either profound faulting must have occurred there or that progressive overlap on an extensive scale must have accompanied the deposition of the beds. In the course of the writer's studies of the Triassic, carried on at intervals during the past six years, some evidence bearing on this point has been accumulated.[2]

As shown elsewhere,[3] the Triassic of Pennsylvania can be divided into three formations, which from the base upwards are: the Stockton (Norristown) arkosic sandstone and conglomerate, 5,500 feet in maximum thickness, which outcrops along the southern edge of the belt; the Lockatong (Gwynedd) dark shale, which appears as a lens between the other two, 3,500 feet thick at the Dela-

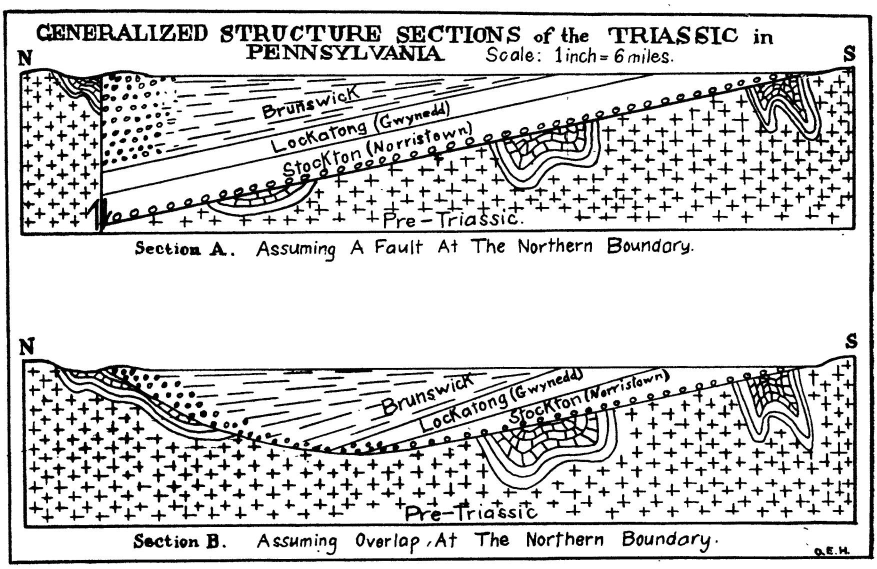
[1] *Geology of Pennsylvania*, II, p. 814, 1858.

[2] This was presented in abstract at the meeting of the Geological Society of America, December 29, 1911 (*Bull. Geol. Soc. Amer.*, XXIII, 745), and at the meeting of the Academy in conjunction with the Mineralogical and Geological Section, May 21, 1912 (*Proceedings*, 1912, p. 156), but is now for the first time published in full.

[3] Age and Correlation of the "New Red" or Newark Group in Pennsylvania, *Proc. Acad. Nat. Sci. Phila.*, 1912, pp. 373–379.

ware River, gradually thinning westward, and dying out in northern Chester County, but reappearing north of Lancaster and represented by 1,000 feet of carbonaceous sandstones at the Susquehanna; and the Brunswick red shale and conglomerate, up to 16,000 feet thick, which lies against the older rocks along the northern boundary. Although the evidence is not sufficient for definite correlation, it seems probable that these are roughly equivalent to the Bunter, Lower Keuper, and Upper Keuper of Europe, respectively.

The following sections represent two alternative explanations of the structure of the Triassic basin in this region.



GENERALIZED STRUCTURE SECTIONS of the TRIASSIC in PENNSYLVANIA Scale: 1 inch = 6 miles.

Section A. Assuming A Fault At The Northern Boundary.

Section B. Assuming Overlap, At The Northern Boundary.

It is believed that Section B most correctly depicts the relationships existing through the greater part of the Pennsylvania Triassic area, although in Connecticut and in northern New Jersey sections of the type of A have been thought to accord best with the observed facts. This conclusion is based, first, on studies of the actual contacts exposed along the northern boundary and, second, on certain inferences drawn from features shown by the rocks in other portions of the area.

While the northern boundary of the Triassic against the older rocks is usually marked by a slight depression and deeply covered by soil, more or less definite contacts can be seen in at least six places, namely, Monroe on the Delaware; Springtown, Bucks

County; Boyertown, Berks County; south of Reading, on the Schuylkill; Cornwall, Lebanon County, and on the west bank of the Susquehanna below New Cumberland. The writer's studies have not been extended southwest of the Susquehanna River, but Mr. George W. Stose, of the U. S. Geological Survey, who has traced the line through the Fairfield Quadrangle, states (private communication) that overlap relations occur there also.

The exposures at Monroe, a small village on the west bank of the Delaware River along the Easton-Philadelphia trolley line, nine miles south of the former place, have been studied and described by Dr. H. B. Kümmel.[4] The Brunswick conglomerate appears to overlie a bluish-gray (probably Cambrian) limestone, although the actual contact is covered by talus, and he regards it as probable that overthrust faulting has occurred. There is admittedly no direct evidence of this, but even if it does exist, it must be of very limited extent, and can have no bearing on the relation of the formations as a whole, because the fault-boundary shown in Section A would be of normal type and many thousands of feet in throw. About 500 feet south of the first exposure a ledge of white rock appears at the base of the trolley cut, and is solidly overlain by the Triassic conglomerate. This may represent only a local phase of the Triassic itself, and, if so, has no significance, but it may also possibly be pre-Triassic limestone, in which case the existence of a fault is out of the question.

About a mile and a half southeast of Springtown, Bucks County, five miles southwest of the Delaware, what appears to be a contact is exposed in the bed of a brook. A rounded ledge of a yellowish quartzite similar in all respects to the Cambrian (Hardyston) of the region, at least 12 feet long and 4 feet wide, shows fragments of typical Triassic conglomerate solidly welded to it. It is true that neither rock can be traced to solid connection with the main exposures in the vicinity, and the quartzite may not be in place, but it is too large a mass to have been carried far.

For some twenty miles southwest of this point nothing that can be regarded as a definite contact has been discovered, and there are reasons for believing that locally slight faults occur, but at several places in the vicinity of Boyertown, Berks County, overlap relations are again shown. As noted by Dr. Spencer,[5] along the road

[4] *Ann. Rept. State Geol. N. J.*, 1897, pp. 111, 112.

[5] Magnetite Deposits of the Cornwall Type in Pennsylvania, *Bull. U. S. Geol. Surv.*, No. 359, p. 64, 1908.

in the valley of West Swamp Creek, southeast from Bechtelsville, metamorphosed shales—"baked shales which may belong to the Mesozoic"—overlie blue Paleozoic limestones. The exposure is not a good one, yet there can be no doubt that actual overlap occurs.

Additional evidence for this vicinity is furnished by a well record described by D'Invilliers[6] as follows: "From the Montgomery county line, at A. Schultz's house, [three miles northeast of Bechtelsville] . . . . to the north border of the Mesozoic, is a distance of 6,400 feet; the average dip, 30°; calculated thickness of Mesozoic at Schultz's, 3,000 feet; nevertheless, Mr. Schultz's water well struck the limestone floor beneath the Mesozoic at less than 200 feet." The supposed outlying patch of limestone, "left bare by the denudation of the thin covering of red shale" (*ibid.*, p. 205) appears, however, to be a calcareous conglomerate bed in the Triassic itself.

In the extensive Boyertown iron mines the limestones bearing the ore were everywhere found to underlie the Triassic beds.[7]

Continuing southwestward twelve miles, there is again evidence of the existence of a local fault, as pointed out by the writer elsewhere,[8] but in a trolley cut about a mile from the Schuylkill River an apparent overlap is poorly exposed, and then at the Big Dam, northwest of Neversink Station, is the erosion contact described by Rogers.[9] Here a fissure in the limestone into which pebbles of the conglomerate had been washed was formerly exposed. At present the quarry shows conglomerate composed of but slightly rounded limestone pebbles cemented together by a minimum quantity of red mud resting on a somewhat brecciated limestone, into the cracks of which more or less red mud has percolated, so that it requires very close examination to make out the real contact. In the old iron mine on Fritz's Island, around the bend in the river, and at the Wheatfield mine, seven miles to the west, ore-bearing limestone and sandstone were found beneath the Triassic beds as at Boyertown.[10]

At the great Cornwall iron mine, in Lebanon County, twenty miles further west, Triassic conglomerate overlies, on the south

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[6] Geology of the South Mountain Belt of Berks County, *Second Penna. Geol. Surv. Rept. D3*, II, pt. 1, p. 200, 1883.

[7] Spencer, *op. cit.*, pp. 43–60.

[8] Contributions to the Mineralogy of the Newark Group in Pennsylvania, *Trans. Wagner Free Inst. Science, Phila.*, VII, pp. 1–23, 1910.

[9] *Geology of Pennsylvania*, II, p. 681, and fig. 568, 1858.

[10] D'Invilliers, *op. cit.*, pp. 336, 337, and 346.

side, the Paleozoic strata bearing the ore,[11] and, since diamond drilling has shown that ore extends well under this cover, the Middle Hill workings are now being extended in that direction. Spencer[12] discussed the probability of there having been progressive overlap here, and published several cross-sections exhibiting this relation.

The last exposure of this contact found by the writer is twenty miles west of Cornwall, on the west bank of the Susquehanna River, one and a half miles below the town of New Cumberland. Here, in the Northern Central Railroad cut, the Triassic conglomerate is in solid contact with the limestone, and specimens showing a "welding" of the two were secured. The plane of contact here slopes more steeply than usual, perhaps 45° to the south, while the conglomerate beds dip about 20° northward.

It thus appears that all along the line through Pennsylvania the highest beds of the Triassic, usually coarse-grained conglomerates, overlap upon the older rocks—limestones, quartzites, and gneisses. The few faults which can be recognized are too limited in extent to have any bearing on the question as to the position of the beds as a whole.

That the several formations of the Triassic were not deposited regularly and evenly on top of one another can also be inferred from the observed lack of anything like metamorphism—cementation, induration, crystallization—of the lowermost (Stockton) beds. Had these ever been buried beneath the whole 20,000 feet of the two overlying formations, the temperature would necessarily have been raised so high and opportunities for chemical action have become so great, that some changes would surely have been produced. Again, the Stockton is known to thin rapidly northward. Its thickness along the southern edge of the belt, toward the eastern end, is as great as 5,500 feet, but where brought to the surface by the Buckingham Mountain fault (the Flemington fault of New Jersey), ten miles further north, it is only about 2,000 feet.

It is therefore believed that in the portion of the Triassic basin crossing eastern Pennsylvania the locus of deposition of the beds was gradually shifted northward during the course of the period, so that the successive formations overlapped more and more to the north, the basin being deepened by down-warping rather than by faulting, as brought out by Section B.

[11] Lesley and D'Invilliers, *Ann. Rept. Second Penna. Geol. Surv.*, 1885, pp. 491–570.

[12] *Op. cit.*, pp. 20, 21, pl. III.

It has several times been mentioned above that the uppermost beds of the Triassic are, in general, conglomerates. But as this term may cover rocks of quite a variety of characters and origins, it seems worth while to describe them more definitely. For this purpose those developed along the northern boundary for twenty miles westward from the Delaware River have been selected, since they are believed to be typical of the formation, and since, by reason of their accessibility, it has been found possible to study them in the greatest detail.

The most striking feature of the Triassic area in northern Bucks and southern Northampton and Lehigh Counties is the occurrence of rather prominent hills, the highest attaining 980 feet above tide, or 500 feet above the usual level of the red-shale region, and exceeding those formed by both the diabase and gneiss, usually regarded as the most resistant of rocks, in the immediate vicinity. On these hills, in spite of deep dissection and frequent steep slopes, very few exposures of rock in place are found, although the soil is strewn with boulders and pebbles of pink-stained quartzite. This material has been previously interpreted in three ways, as Cambrian (Chickies or Hardyston), Ordovician (Shawangunk or Green Pond), and metamorphosed Triassic. The present view of the matter is that, while the quartzite of the pebbles is actually of the second of these ages, the pebbles themselves are not of recent origin, but have weathered out of a conglomerate belonging to the ordinary, unmetamorphosed Triassic series.

This conclusion has been reached as follows: At a few places along the hill slopes and at two localities where prospecting for copper has been carried on, the rock can be seen in place. It consists of a soft red mud ground mass in which are imbedded pebbles of all sizes up to two feet in diameter, but mostly around three inches, rudely but evidently assorted and stratified. The largest and most thoroughly rounded of these consist of a gray to pink quartzite, often in itself conglomeratic—containing white quartz grains up to half an inch across, and occasional flakes of gray slate. These quartzite pebbles are usually stained deep red by a film of hematite, which penetrates the cracks and spreads out around them in rounded, imperfectly dendritic patches. At the copper prospects above mentioned they also show abundant malachite stains, which in at least one specimen seemed to be derived by weathering of a copper sulfide originally imbedded in the quartzite itself, but now leached out, leaving tiny holes.

Lithologically, this quartzite is in every way identical with the Shawangunk, which forms Blue Mountain twenty miles away to the north, and with the Green Pond conglomerate of the same age, occurring in the highlands of northern New Jersey. Not only does this similarity cover the general features of the rock, but it extends down to such small details as the extent of the silicification visible under the microscope, the inclusion of the gray slate flakes, and the occasional presence of copper sulfides (chalcocite?) in minute disseminated grains, just as occurs at the Pahaquarry copper mine on Blue Mountain, eight miles northeast of the Delaware Water Gap. And since there is no other formation anywhere in the region of at all similar lithologic character, there would seem to be no reasonable doubt as to the correctness of this interpretation.

In addition to these quartzite pebbles, limestone fragments are often present in the conglomerates, locally forming almost the only constituent of the rock. These are usually less well rounded than the quartzite, and, in fact, are often so angular that the rock should be termed a breccia. When exposed to atmospheric agencies they have usually weathered out, leaving a peculiar-looking cellular rock. Nothing has been observed to indicate that these limestone pebbles are of different type from the Paleozoic (Cambrian and Lower Ordovician) strata exposed in the valleys to the north; in fact, streaks of the black chert so frequently present in these beds have been noted in some of the pebbles. Along with the limestone pebbles are also abundant flakes of a greenish schistose material, which resembles the sericite partings developed in the limestones in many places, occasional beds of the conglomerate being made up of nothing but overlapping chips of this schist.

Again in some places, gneiss pebbles are present in considerable numbers, several of the types now exposed in the hills to the north being represented. These, like the limestone fragments, are only imperfectly rounded, and they have also weathered on the surface to some extent, although perfectly fresh when seen in recent artificial exposures, as along the trolley line south of Monroe, on the Delaware River.

On descending the hill slopes it is found that the pebbles in the soil become gradually fewer in number, and finally give way to frost-shattered shale fragments, as roughly indicated on the map by the small circles. There is practically no decrease in the sizes of the pebbles going outward from the centers of the hills, and absolutely nothing like a gradation from the conglomerates

through finer and finer sandstones to the ordinary Brunswick shales. The same red sandy mud makes up the bulk of both rocks, the pebbles having simply been dropped into it while still soft. Similar relations appear in four distinct areas, all of the same general type, although the shape of outcrop is modified by diabase intrusions and local variations in the dip of the usually practically horizontal beds.

That these conglomerates have been deposited chiefly under water is shown by the stratification and assorting of the pebbles, rough though it may be, and by the occurrence of interbedded thin laminated shales, which show such features as ripple marks and rill marks. That the water was fresh is indicated by the absence of marine fossils, and perhaps by the red color of the mud. The source, mode of transportation, and of deposition of the pebbles remain to be considered.

Three possibilities at once suggest themselves: we may be dealing with either talus broken from cliffs by wave or frost action, alluvial fans, or glacial moraines.

The first view, that the pebbles are talus blocks, was accepted by Dr. Kümmel[13] in the New Jersey area.

This conclusion is, however, quite inapplicable in the present localities, for it is very evident that the nature of the pebbles bears in general no relation to the character of the rock against which the conglomerate lies. Dr. Kümmel had observed the same thing, and explained it as due to faulting, but, as shown above, this does not occur in the present region. Gneiss pebbles are found most abundantly at Monroe, where the floor is limestone, and limestone pebbles west of Coopersburg, where the underlying rock is gneiss. Indeed, there is now no outcrop of Shawangunk quartzite, such as forms the majority of the pebbles, within twenty miles (although, of course, it may have extended somewhat farther south in Triassic times). Further, the fact that the limestone is less rounded than the much harder quartzite is just the opposite of what would be observed in talus heaps rounded by wave action, but can be explained according to the principle that the degree of rounding increases with the distance of transportation, for the limestone rocks from which the pebbles may have been derived outcrop nearly everywhere within a mile or two of the edge of the basin.

The application of the criteria for the recognition of alluvial-

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[15] *Ann. Rept. State Geologist of N. J.*, 1897, pp. 52–58.

fan deposits, as recently summed up by Trowbridge,[14] to the present occurrences shows the improbability of their having had such an origin; the majority of the pebbles are too well rounded and assorted. In fact, the stratification is quite definite, and the pebbles have apparently been transported and deposited by some agent which did not disturb the soft red mud now forming the cement of the conglomerate.

The possible glacial-moraine origin of similar Triassic conglomerate deposits in other regions has been advanced, in some form or other, by various writers. W. M. Fontaine[15] discussed it elaborately and found no difficulty in reconciling the (supposed) deposition of the bulk of the strata in a "mild, equable and moist climate" in the lowlands, with the collection of "unlimited supplies of snow" and "its discharge in the form of glaciers" on the "lofty mountain belt of the Appalachians." And many others had come to agree with this view. I. C. Russell,[16] after reviewing the evidence, stated that "the absence of glacial records seems to warrant the conclusion that glaciers did not enter the basins in which the Newark rocks were deposited. It does not follow, however, that the Appalachians were not occupied by local glaciers. The suggestion that those mountains were higher in the Newark period than now and were covered with perennial snow, while the adjacent lowlands enjoyed a mild climate, seems an attractive and very possible hypothesis, but definite evidence as to its verity has not been obtained. The proof that the climate of the Atlantic slope during the Newark period resembled that of Italy at the present day, with glaciers on the neighboring mountains, must be looked for in the drainage and sculpturing of the mountains, and the character and distribution of the débris washed from them. A period of long decay preceding the birth of the Appalachian glaciers would have prepared land to furnish abundant débris when the facilities for transportation were augmented."

In late years the idea that the red color of sediments is connected with their deposition in more or less arid climates, has gradually been gaining ground, and as other evidence appeared to favor

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[14] The Terrestrial Deposits of Owens Valley, California, *Jour. Geol.*, XIX, 706–747, 1911.

[15] Notes on the Mesozoic strata of Virginia, *Amer. Jour. Sci.*, [3] XVII, pp. 236, 237, 1879.

[16] Correlation papers—The Newark System, *Bull. U. S. Geol. Surv.* No. 85, pp. 50–53, 1892.

such a view of the origin of the bulk of the Triassic,[17] Russell's "attractive and very possible hypothesis" of glaciation of the Appalachian Mountains in that period has been practically forgotten. It is the writer's belief, however, that "the character and distribution of the débris" forming the conglomerate beds under discussion constitutes a very good argument for its revival.

That the pebbles and boulders were carried down into the Triassic basin along certain definite channels is clearly indicated by the shapes and positions of the conglomerate masses. Something, in fact, can be made out as to the possible routes along which they came. In this region at present the position of streams is controlled to a certain extent by fault or joint systems. Since most of these structural features are, however, evidently pre-Triassic, it is reasonable to suppose that similar depressions existed there then and became at times river channels. It can readily be seen on the map that stream routes (marked by heavy dotted lines) do actually strike the edge of the Triassic belt at or near the centers of the several conglomerate masses, although of course changes of geography since that period have altered the actual direction of the drainage and superficial features. But the boulders in the conglomerates are too large to have been carried by any streams flowing in these channels at the present day and, indeed, as shown above, torrential alluvial-fan origin is improbable. Russell's arguments against a direct glacial origin being also valid, as far as all later observations go, apparently only one possible mode of formation remains—transportation by floating ice.

Evidence favoring this view has been unexpectedly obtained in the course of field work to the southwest of Hellertown. The Saucon Valley, a broad limestone plain which lies to the north of the Triassic highland here, contains extensive deposits of what is regarded as extra-morainic drift. It is believed that in late Quaternary glacial times the Lehigh River was temporarily dammed back and formed a lake—locally called Lake Packer—whose surface reached a height of 450 feet above tide, and which therefore spread over much of Saucon Valley. Floating ice, breaking off from the front of the great glacier, which extended on the Lehigh only to White Haven, over fifty miles north of the present region, came down stream, and some of it was carried by currents around into the Saucon Valley Bay. As this ice gradually melted, numerous well-

[17] Cf. Lull, R. S., The Life of the Connecticut Trias, *Amer. Jour. Sci.*, [4] XXXIII, pp. 397–422, 1912, and the writer, *Proc. Acad. Nat. Sci. Phila.*, 1912, pp. 371, 372.

rounded pebbles and boulders of various Paleozoic rocks, chiefly quartzites, derived from the mountains to the north, were deposited in a rudely stratified sheet over the valley floor in sufficient quantity to almost completely cover the underlying limestone rock.[18]

At the south side of the valley such drift extends just up to the Triassic contact, and many of the drift boulders are essentially similar in size, shape, and degree of rounding to those weathered from the Triassic conglomerate, and in fact can only be distinguished by the color, which is yellow or brown instead of red.

If there were in Triassic times glaciers in the mountains, they must have formed terminal moraines, and drift from these would naturally be occasionally transported on cakes of ice down the streams issuing from the glaciers, and be dropped whenever this ice melted. Some could not fail to be carried out into the shallow lakes or ponds in which the Triassic red muds were being deposited, and would then be dropped into this mud without disturbing its stratification, as we actually find to be the case. Again, as the distance out from the margin of the basin to which the pebbles would be carried have nothing to do with their size, but only with the size of the ice blocks and the resulting rate of melting, they should simply become fewer in numbers, rather than less in size, toward the center of the basin. As noted above, this is exactly what does occur.

It is not intended to imply that all of the materials of these conglomerates had this origin. The smaller, subangular limestone and gneiss pebbles and the green shale-flakes were, no doubt, carried largely by direct stream action. But the writer feels convinced that the features shown by the great mass of quartzite boulders constitute a good indication of the correctness of Fontaine's and Russell's theory that glaciers existed in the Appalachian Mountains during late Triassic times.

SUMMARY.

The shape of outcrop and structure of the three subdivisions of the Pennsylvania Triassic implies either a profound fault on the north side of the basin or progressive overlap in that direction on an extensive scale. The latter view is shown to be the most satisfactory one in this region. The conglomerates developed along

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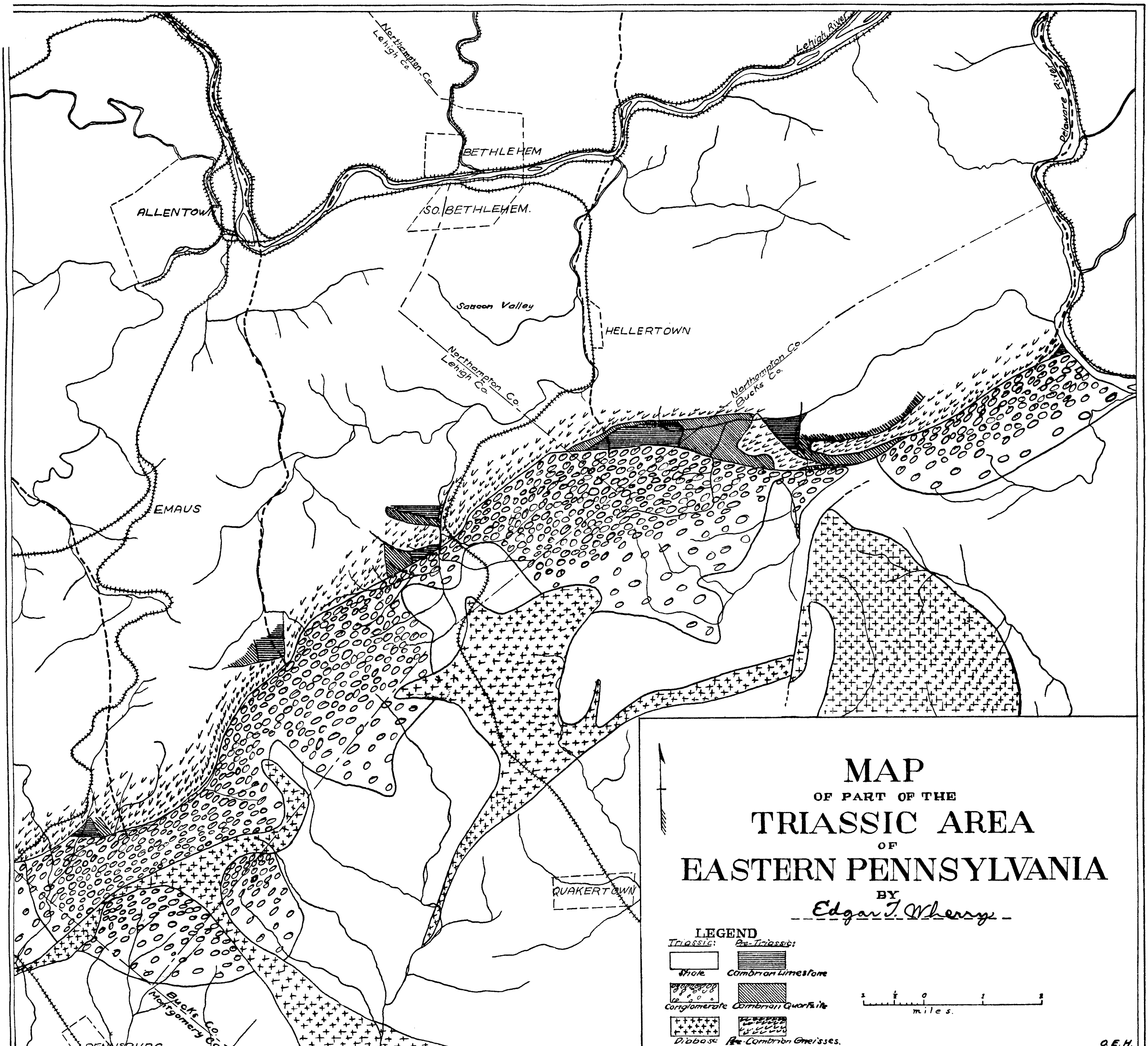
[18] Williams, E. H., Extra-morainic drift between the Delaware and the Schuylkill, *Bull. Geol. Soc. Amer.*, V, 281–295, 1894.

the north border are found to show features which suggest the transportation of a considerable part of their materials by ice floating in streams arising from the melting of glaciers in the Appalachian Mountains to the north.

Explanation of Plate III.

Map of the north border of the Triassic in Bucks, Northampton and Lehigh Counties, Pennsylvania, showing distribution of the border conglomerates and hypothetical stream channels of Triassic times.



WHERRY: TRIASSIC OF PENNSYLVANIA.